Reprinted from the *Soil Science Society of America Journal*
Volume 48, no. 4, July–August 1984
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Tillage and Residue Effects on Wheat, Sorghum, and Sunflower Grown in Rotation[1]

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ABSTRACT

Tillage methods affect soil surface conditions and amounts of crop residue retained on the soil surface, which, in turn, affect water infiltration and subsequent evaporation. The objectives of this study were to determine the effect of tillage methods and wheat residue levels on soil water storage and use, and on crop growth and yields. The study, conducted on Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls), involved an irrigated winter wheat (*Triticum aestivum* L.)-dryland grain sorghum [*Sorghum bicolor* (L.) Moench]-dryland sunflower (*Helianthus annuus* L.) cropping system. A 330-d fallow period occurred between wheat harvest and sorghum planting and a 210- to 270-d fallow period (overwinter) occurred between sorghum harvest and sunflower planting. Wheat was planted 30 to 60 d after sunflower harvest. After wheat harvest, residues were partially removed from one-half of the plots; residues on the other half were not removed. Then, moldboard-, disk-, rotary-, sweep-, and no-tillage treatments were applied. Soil water content increases during fallow after wheat averaged 89, 109, 85, 114, and 141 mm for the respective tillage treatments, and averaged 97 and 118 mm for the low and high residue treatments. Precipitation averaged 316 mm during fallow. The differences in stored water significantly affected sorghum growth; grain and forage yields; and seed test weight, weight/seed, and protein. Sorghum grain yields averaged 2.56, 2.37, 2.19, 2.77, and 3.34 Mg/ha with the respective tillage treatments. The tillage treatments had no residual effect on subsequent sunflower and wheat yields. However, including sunflower in the rotation apparently allowed extraction of water from deeper in the profile than that extracted by sorghum, thus increasing the utilization of water resources for crop production. In addition, the earlier harvest date for sunflower allowed wheat to be planted at a more optimum time than that which is possible when wheat is planted after grain sorghum harvest.

Additional Index Words: **water conservation, conservation tillage, no-tillage, *Sorghum bicolor*, *Helianthus annuus*, *Triticum aestivum*, soil water storage, soil water use.**

Unger, Paul W. 1984. Tillage and residue effects on soil water and crop factors in a winter wheat-sorghum-sunflower rotation. Soil Sci. Soc. Am. J. 48:885–891.

VARIOUS TYPES of primary tillage are used for crop production in the southern Great Plains. These range from moldboard plowing, which buries most crop residues, to various types of conservation tillage, including no-tillage, which maintains crop residues on the soil surface.

Different amounts of surface residues have resulted in different amounts of precipitation stored as soil water (Baumhardt, 1980; Greb et al., 1967, 1970; Mannering and Meyer, 1963; Meyer et al., 1970; Musick et al., 1977; Unger, 1978a; Unger et al., 1971; Unger and Wiese, 1979). Different tillage methods also result in different physical conditions of the surface soil, which also affect water infiltration (Burwell and Larson, 1969; Edwards and Larson, 1969; Falayi and Bouma, 1975; Foster et al., 1982; Johnson et al., 1979; Moore and Larson, 1979) and subsequent loss by evaporation (Linden, 1982). The effect of tillage methods on soil physical conditions and grain sorghum [*Sorghum bicolor* (L.) Moench] emergence was investigated in another phase of this study (Unger, 1984). The objectives of this phase of the study were to determine the effect of tillage methods and residue levels on soil water storage and use, and on crop growth and yields.

MATERIALS AND METHODS

The study was conducted in field plots at the USDA Conservation and Production Research Lab., Bushland, Texas, from 1978 to 1983. Soil of the study area was Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) with a uniform 0.3% slope. The soil is very slowly permeable because of a dense B22t horizon high in montmorillonitic clay at a depth of about 0.23 to 0.61 m. Based on −0.033- and −1.5-MPa matric potentials, the soil has a plant available water storage capacity of about 230 mm to a 1.8-m depth, the depth to which winter wheat (*Triticum aestivum* L.) with a well-developed root system often extracts water from this soil.

The study involved an irrigated winter wheat–dryland grain sorghum–dryland sunflower (*Helianthus annuus* L.) rotation. A 330-d fallow period occurred between wheat harvest and sorghum planting and a 210- to 270-d fallow period (overwinter) occurred between sorghum harvest and sunflower planting. Wheat was planted 30 to 60 d after sunflower harvest. The various operations and periods involved are given in Table 1. Initial treatments were imposed after wheat harvest on a uniformly managed area in July 1978. The same treatments were imposed on similarly treated adjacent areas in 1979 and 1980. The final wheat crops, which completed the rotation on each area, were harvested in 1981, 1982, and 1983. Wheat harvest dates were around 1 July.

The furrow-irrigated wheat, which was grown before plot establishment on a given area, yielded 2.63, 3.95, and 3.16 Mg of grain/ha and 5.4, 6.3, and 5.2 Mg of residue/ha in 1978, 1979, and 1980, respectively. Irrigation furrow spacing for the wheat was 1.0 m and drill row spacing was 0.25 m.

After wheat harvest, plots were established for two levels of wheat residues and five tillage methods. The study had a randomized block, split plot design with three replications of the treatments. Tillage main plots were 8 m (eight 1-m-spaced ridge-furrows) wide and 120 m long. Residue level subplots were 4 m wide and 120 m long. Residue level treat-

Table 1—Months and years in which operations were performed or fallow periods occurred in a winter wheat-grain sorghum-sunflower crop rotation at Bushland, Texas.

Operation or period	Crop area 1	Crop area 2	Crop area 3
Harvest initial wheat	July 1978	July 1979	July 1980
Fallow—wheat to sorghum	July 1978–June 1979	July 1979–June 1980	July 1980–June 1981
Plant sorghum	June 1979	June 1980	June 1981
Harvest sorghum	Sept 1979	Oct 1980	Nov 1981
Fallow—sorghum to sunflower	Sept 1979–June 1980	Oct 1980–June 1981	Nov 1981–June 1982
Plant sunflower	June 1980	June 1981	June 1982
Harvest sunflower	Aug 1980	Sept 1981	Aug 1982
Plant wheat	Oct 1980	Oct 1981	Sept 1982
Harvest final wheat	July 1981	July 1982	June 1983

[1] Contribution from USDA, Agricultural Research Service, Bushland, TX 79012. Received 19 Dec. 1983. Approved 19 Mar. 1984.
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ments consisted of no removal of residues and removal of most of the standing wheat residues before imposing the tillage treatments. Residues were removed with a flail-type forage harvester with the blades operated 30 to 50 mm above the soil ridges. The amounts removed averaged 2.2, 1.7, and 1.5 Mg/ha in 1978, 1979, and 1980, respectively.

Tillage treatments were moldboard-, disk-, rotary-, sweep-, and no-tillage. Moldboard- and rotary-tillage were used only for initial tillage. Thereafter, disk- and sweep-tillage, respectively, followed the above operations as needed (two or three times) for weed control. On disk- and sweep-tillage plots, these operations were repeated as needed (three or four times) for weed control. Tillage depths were about 0.15 and 0.10 m for initial and secondary operations, respectively.

On no-tillage plots, weeds were controlled with atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine][3] and 2,4-D[(2,4-dichlorophenoxy) acetic acid][3] applied at rates of 0.34 and 0.11 g/m^2, respectively, soon after wheat harvest. Terbutryn [2-(*tert*-butylamino)-4-(ethylamino)-6-(methylthio)-*s*-triazine][3] was applied at a 0.34-g/m^2 rate to all plots for additional weed control during the sorghum growing season. The herbicide was incorporated with a rolling cultivator on tillage plots, but was not incorporated on no-tillage plots. The rolling cultivator with furrow openers also formed 1-m-spaced ridges and furrows on all except the no-tillage plots. On the latter, ridges and furrows remained intact from the previous wheat crop.

Precipitation was measured at the plot area with a standard (200-mm diam) rain gauge. Two soil core samples were obtained from each plot for gravimetric water content determination after the initial wheat harvest and at sorghum and sunflower planting and harvest. Sampling increments were 0.30 m to a 1.8-m total depth. Water contents were not determined after the final wheat crops because the wheat was uniformly managed and soil water contents were not significantly different at sunflower harvest.

Sorghum was planted 13, 26, and 4 June in 1979, 1980, and 1981, respectively. The sorghums were DeKalb medium maturity hybrids 'C46+', 'C42y+', and 'DK42y' in the respective years and were planted on the ridges with unit planters having double-disk openers. Depth bands on the openers resulted in seed placement at about a 38-mm depth. The intended plant population was about 96 000 plants/ha, but extra seed drop resulted in higher populations in some cases (Unger, 1984). Plant heights were measured during the growing season and grain-bearing panicles were counted when samples for grain yield were hand-harvested from two 3 m long row sections from each of the two center rows of each plot. Samples for forage yield were obtained from the same areas. After oven-drying at 50°C, grain was threshed from the panicles and grain yield, test weight, weight per seed, and protein content were determined. Subsamples of forage were also dried at 50°C for determining moisture contents for use in yield calculations. Data are reported on an oven-dry weight basis.

[3] Mention of a trade name or product does not constitute a recommendation or endorsement for use by the U. S. Dep. of Agriculture, nor does it imply registration under FIFRA as amended.

Table 2—Precipitation during the various periods of a winter wheat-grain sorghum-sunflower crop rotation at Bushland, Texas, 1978–83.

Period†	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for period	Long-term avg. for period
	mm													
Fallow (Wh to Sorg)														
1978–1979	14	8	25	10	58		13	40	156	7	24	0	355	392
1979–1980	17	0	39	19	110		49	68	5	40	12	0	359	392
1980–1981	0	0	54	6	33		32	43	28	28	9	0	233	392
Avg.	11	3	39	12	67		31	50	63	25	15	0	316	392
Sorghum GS														
1979						97	49	68	5				219	257
1980						28	32	43	28	28			159	298
1981						126	23	143	123	82	28		525	317
Avg.						84	35	85	52	55	28		301	291
Fallow (Sorg to SF)														
1979–1980	17	0	39	19	110					40	12	0	237	212
1980–1981	0	0	54	6	33						9	0	102	172
1981–1982	0	0	6	14	70							0	90	163
Avg.	6	0	33	13	71					40	11	0	143	182
Sunflower GS														
1980						28	32	43					103	212
1981						126	23	143					292	212
1982						99	123	10					232	212
Avg.						84	59	65					209	212
Wheat GS														
1980–1981	0	0	54	6	33	126			28‡	28	9	0	275	330
1981–1982	0	0	6	14	70	99			123‡	82‡	28	0	422	330
1982–1983	33	33	14	18	44	24			39‡	27	10	16	258	330
Avg.	11	11	25	13	49	83			63	46	16	5	318	330
44-yr avg. (1939–82)	11	12	19	28	69	75	66	71	45	41	19	13		467

† Abbreviations used are as follows: Wh = wheat, Sorg = sorghum, GS = growing season, and SF = sunflower.
‡ Precipitation in September each year and 42 mm of the precipitation in October 1981 occurred during the interval from sunflower harvest to wheat planting, and is included in the growing-season total for wheat.

None of the plots was plowed during the period from sorghum harvest to sunflower planting. Weeds were not a problem during late fall and winter; however, 2,4-D at 0.06 g/m^2 and metolachlor [2-chloro-N-(2-ethyl-6-methylphenol)-N-(2-methoxy-1-methylethyl) acetamide][3] at 0.34 g/m^2 were applied in spring for weed control. In 1980, sunflower was cultivated once for additional weed control.

Sunflower 'hybrid 894' was planted with unit planters in early June 1980, 1981, and 1982 by the no-tillage method. The unit planters were equipped with double-disk openers. The sunflower was planted on the ridges remaining from the previous sorghum crop, but slightly to one side of the sorghum crowns to improve soil penetration and seed coverage. Intended plant populations were about 32 000 plants/ha. Sunflower yields were determined from samples harvested by hand from two 3 m long row sections at two sites per plot. After oven-drying at 50°C, the head samples were threshed and seed yield, test weight, weight per seed, and oil content were determined. Data are reported on an oven-dry weight basis.

Immediately after sunflower harvest in late August or early September, stalks were shredded and plots were uniformly disked twice. Anhydrous ammonia was applied at a rate to provide 170 kg N/ha and ridges and furrows were established by disk bedding or listing in preparation for planting wheat. In 1980 and 1981, an irrigation was applied before planting wheat. No irrigation was needed in 1982 because of favorable precipitation. In all years, a rolling cultivator was used to shape the ridges before planting wheat.

'TAM105' winter wheat was planted on 17 Oct. 1980, 6 Oct. 1981, and 22 Sept. 1982 with a single-disk-opener drill with 0.25-m drill row spacings. Planting rate was 85 kg/ha. The wheat was irrigated two to four times during the growing season, depending on precipitation amounts, for a moderate yield level.

Data were analyzed by the analysis of variance technique. When the F-test indicated statistical significance, the Duncan's Multiple Range Test (LeClerg et al., 1962) or the Protected LSD (least significant difference) (Steel and Torrie, 1980) was used to indicate which differences were significant.

RESULTS AND DISCUSSION

Precipitation

Monthly precipitation data are given in Table 2 for the different fallow and cropping periods. Also shown are the long-term (1939–82) monthly averages and the long-term totals corresponding to the different periods. The different periods did not start or end at the start or end of a month as suggested by data in the table; however, precipitation amounts shown include that which occurred for the given period. Some ad-

Table 3—Soil water contents, changes, and storage efficiencies at various times and/or during various periods of a winter wheat-grain sorghum-sunflower crop rotation at Bushland, Texas, 1978–83.

Water content factor and time or period†	Residue level	Tillage method‡							
		M	D	R	S	NT	Avg.	Years or period	Average§
At initial Wh harvest—mm	Low	61	53	54	68	63	60a¶	1978	84a¶
	High	58	46	64	61	67	59a	1979	39c
	Avg.	60a¶	50a	59a	65a	65a		1980	56b
Change during fallow (Wh to Sorg)—mm	Low	78	105	84	98	121	97b	1978–79	90b
	High	100	112	85	130	161	118a	1979–80	143a
	Avg.	89b	109b	85b	114ab	141a		1980–81	90b
Storage efficiency (Wh to Sorg)	Low	0.25	0.33	0.27	0.31	0.38	0.31b	1978–79	0.25b
	High	0.32	0.35	0.27	0.41	0.51	0.37a	1979–80	0.39a
	Avg.	0.29b	0.34ab	0.27b	0.36ab	0.45a		1980–81	0.38a
At Sorg planting—mm	Low	139	158	138	166	184	157b	1979	174a
	High	158	158	148	191	229	177a	1980	182a
	Avg.	149c	158bc	143c	179b	207a		1981	145b
At Sorg harvest—mm	Low	91	94	89	90	102	93a	1979	47c
	High	88	99	86	99	111	97a	1980	87b
	Avg.	90b	97b	88b	95b	107a		1981	151a
Change during Sorg GS—mm	Low	−48	−65	−49	−77	−82	−64a	1979	−127c
	High	−70	−59	−63	−92	−118	−80b	1980	−95b
	Avg.	−59ab	−62ab	−56a	−85bc	−100c		1981	+6a
Change during fallow (Sorg to SF)—mm	Low	83	100	92	111	107	99a	1979–80	179a
	High	86	97	102	106	104	99a	1980–81	59b
	Avg.	85a	99a	97a	109a	106a		1981–82	59b
Storage efficiency (Sorg to SF)	Low	0.58	0.70	0.64	0.78	0.75	0.69a	1979–80	0.78a
	High	0.60	0.68	0.71	0.74	0.73	0.69a	1980–81	0.60a
	Avg.	0.59a	0.69a	0.68a	0.76a	0.74a		1981–82	0.69a
At SF planting—mm	Low	174	194	181	201	209	192a	1980	226a
	High	174	196	188	205	215	196a	1981	146b
	Avg.	174c	195abc	185bc	203ab	212a		1982	210a
At SF harvest—mm	Low	82	77	69	62	112	80a	1980	67a
	High	68	58	75	51	109	72a	1981	94a
	Avg.	75a	68a	72a	57a	111a		1982	67a
Change during SF GS—mm	Low	−92	−117	−112	−139	−97	−111a	1980	−158b
	High	−106	−138	−113	−154	−106	−124a	1981	−52a
	Avg.	−99a	−128a	−113a	−147a	−102a		1982	−142b

† Abbreviations are as follows: Wh = wheat, Sorg = sorghum, precip = precipitation, GS = growing season, and SF = sunflower.
‡ Tillage methods are as follows: M = moldboard, D = disk, R = rotary, S = sweep, and NT = no-tillage.
§ Values are the yearly averages for all tillage and residue level treatments.
¶ Row or column values followed by the same letter or letters are not significantly different at the 5% level based on the Duncan multiple range test.

Table 4—Growth, yield, and quality factors for crops in a winter wheat-grain sorghum-sunflower rotation at Bushland, Texas, 1978–83.

Factor, and year	Mold-board	Disk	Rotary	Sweep	No-tillage	Avg.
			Grain sorghum			
Plant height—m						
1979	1.04	1.04	0.98	1.08	1.09	1.05a†
1980	0.80	0.83	0.78	0.85	0.86	0.82c
1981	0.94	0.92	0.92	0.86	0.88	0.90b
Avg.	0.93a†	0.93a	0.89b	0.93a	0.94a	
Protected LSD‡ (tillage × year—0.05 level) = 0.05 m						
Panicles—1000's/ha						
1979	213	206	201	217	210	209a
1980	121	136	128	141	146	134c
1981	155	264	224	186	146	195b
Avg.	163c	202a	184b	181b	167c	
Protected LSD (tillage × year—0.05 level) = 24 000/ha						
Grain yield —Mg/ha						
1979	3.68	3.43	2.91	3.68	3.93	3.53a
1980	1.02	1.08	0.93	1.23	1.63	1.18b
1981	2.98	2.61	2.72	3.40	4.45	3.23a
Avg.	2.56bc	2.37cd	2.19d	2.77b	3.34a	
Protected LSD (tillage × year—0.05 level) = 0.39 Mg/ha						
Forage yield —Mg/ha						
1979	3.43	2.93	3.13	3.34	3.19	3.20b
1980	2.57	3.34	2.87	3.71	3.71	3.24b
1981	5.81	9.37	8.22	8.18	7.17	7.75a
Avg.	3.94c	5.21a	4.74b	5.08ab	4.69b	
Protected LSD (tillage × year—0.05 level) = 0.75 Mg/ha						
Test weight —g/L						
1979	860	858	862	854	867	860a
1980	841	841	836	847	852	843a
1981	857	823	831	854	868	847a
Avg.	853b	841c	843c	852b	862a	
Protected LSD (tillage × year—0.05 level) = 14 g/L						
Weight/ seed—mg						
1979	14.2	13.8	13.7	14.1	14.9	14.1c
1980	25.2	27.1	25.2	28.5	26.3	26.5a
1981	21.0	19.7	19.7	22.4	22.5	21.1b
Avg.	20.1b	20.2b	19.5b	21.7a	21.2a	
Protected LSD (tillage × year—0.05 level) = 1.5 mg						
Seed protein concentration —g/kg						
1979	153	153	162	153	153	155a
1980	137	134	139	138	132	136b
1981	111	116	118	118	113	115c
Avg.	134bc	134bc	140a	136b	133c	
			Sunflower			
Plant height—m						
1980	1.34	1.32	1.32	1.27	1.28	1.31a
1981	1.18	1.17	1.18	1.23	1.23	1.20b
1982	1.27	1.37	1.31	1.33	1.28	1.31a
Protected LSD (tillage × year—0.05 level) = 0.06 m						
Heads—1000's/ha						
1980	45	40	43	49	44	44a
1981	29	32	29	33	33	31b
1982	31	31	29	32	31	31b
Avg.	35a	34a	34a	38a	36a	
Seed yield —Mg/ha						
1980	2.00	2.03	2.20	1.90	1.79	1.98a
1981	1.70	1.66	1.71	1.87	1.91	1.77a
1982	0.96	1.08	1.19	1.05	0.92	1.04b
Avg.	1.55a	1.59a	1.70a	1.61a	1.54a	
Seed test weight—g/L						
1980	471	450	449	483	467	464a
1981	473	470	474	474	473	473a
1982	314	310	311	307	312	311b
Avg.	419a	410a	411a	421a	417a	
Protected LSD (tillage × year—0.05 level) = 16 g/L						
Weight/seed —mg						
1980	39.8	44.1	42.2	36.9	42.7	41.1a
1981	44.4	41.8	43.9	43.2	44.7	43.6a
1982	37.1	36.3	36.3	32.9	36.9	35.9b
Avg.	40.4a	40.7a	40.8a	37.7a	41.4a	
Seed oil concentration —g/kg						
1980	449	423	439	455	440	441a
1981	445	454	451	457	443	450a
1982	322	328	333	324	325	326b
Avg.	405a	402a	408a	412a	403a	

† Row or column values for any crop or factor followed by the same letter or letters are not significantly different at the 5% level (Duncan's Multiple Range Test).

‡ Protected LSD (Least Significant Difference) values denote the differences among tillage treatment and year values required for statistical significance. Where the Protected LSD's are not given, the interaction term was not significant at the 5% level.

ditional comments regarding precipitation will be made relative to water storage and use and crop growth and yields.

Soil Water Contents

Soil water contents in plots established after harvest of the initial wheat crops were, as expected, not significantly different (Table 3). Thereafter, tillage methods resulted in significant water content differences at sorghum planting and harvest, and at sunflower planting. Also significant due to tillage were the changes in water content during fallow from wheat to sorghum, water storage efficiency during this fallow, and changes during the sorghum growing season. Residue level treatments significantly affected these same factors, except soil water content at sorghum harvest and at sunflower planting. The high residue treatment resulted in a higher water content, greater change, and a higher water storage efficiency than the low residue treatment.

The no-tillage treatment resulted in the greatest water storage during fallow from wheat to sorghum and, therefore, resulted in the highest water content at sorghum planting and higher water storage efficiency. The next highest values resulted from sweep-tillage. Similarly low values resulted from moldboard-, disk-, and rotary-tillage. The differences in water content at sorghum planting resulted in different amounts of water use during the sorghum growing season, with use values being in the same order as the content values at sorghum planting. Although the water content change during the sorghum growing season was greatest with no-tillage, the content at sorghum harvest was also highest with no-tillage. The higher soil water contents with no-tillage very likely persisted throughout the growing season and, therefore, were largely responsible for the higher sorghum grain yields (Table 4).

Water content changes during fallow from sorghum harvest to sunflower planting were not significant. Therefore, the significant water content differences at sunflower planting resulted primarily from the differences that prevailed at sorghum harvest.

In addition to the significant water content differences among years after harvest of the initial wheat crop, differences among years were also significant for most determined factors. Exceptions were for water storage efficiency during fallow from sorghum to sunflower and for water content at sunflower harvest.

The soil water content differences among years resulted from differences in amount and distribution of precipitation (Table 2). Below-average precipitation during the 1980–81 fallow after wheat resulted in a small change during fallow and a low plant available water content at sorghum planting in 1981. However, the water storage efficiency during that fallow period was greater than for the 1978–79 period when more precipitation occurred, but the initial water content was also higher. Below-average precipitation during the 1980-81 fallow from sorghum to sunflower resulted in the low water content at sunflower planting in 1981. The high water content at sunflower planting in 1982 resulted from the high content at sorghum harvest in 1981, even though precipitation and water content change during the 1981–82 fallow from sorghum to sunflower were relatively low.

Above-average precipitation during the 1981 sorghum growing season resulted in a high water content at sorghum harvest and a net gain in water content from planting to harvest. It also contributed to the relatively high water content at sunflower planting in 1982.

Crop Growth, Yield, and Quality

Although residue level treatments significantly affected soil water contents and changes (Table 3), these treatments did not significantly affect any measured crop factor, except sunflower plant height. Therefore, the values reported in Table 4 are averages for the residue level treatments.

Grain Sorghum

Plant heights were measured throughout the growing seasons. However, no major trends were apparent during any season, except that plants were shorter on rotary-tillage plots in 1979 and 1980, and on sweep- and no-tillage plots in 1981 than on other plots. Detailed data are not shown, but final height values are given in Table 4.

The number of emerged seedlings averaged 127, 123, and 113 thousand/ha in 1979, 1980, and 1981, respectively (Unger, 1984). However, plant tillering resulted in harvested panicles exceeding emerged seedlings by 65, 9, and 73% in 1979, 1980, and 1981, respectively (Table 4). Differences among treatments were not significant in 1979, but the average number of panicles was highest that year. In 1980, when panicle numbers were low because of limited tillering, the values for moldboard- (lowest) and no-tillage (highest) were significantly different. Panicle numbers were low for moldboard- and no-tillage treatments in 1981, and significantly higher in turn for sweep-, rotary-, and disk-tillage treatments. In 1981, severe water stress occurred in July. Stress appeared least severe on no-tillage plots. Above-normal rainfall starting in early August resulted in major tillering on disk-, rotary-, and sweep-tillage plots, but relatively little on moldboard- and no-tillage plots. Tillering was low on moldboard-tillage plots, probably because the plants had undergone major stress and, therefore, did not fully recover in response to the above-normal rainfall. On no-tillage plots, stress was least and tillering was relatively low. Tillering of plants on no-tillage plots probably was limited because these plants were at a more advanced stage of maturity than those on other plots when the rainfall occurred. Even with fewer tillers, yields were highest with no-tillage in 1981 because of the lower plant water stress during July.

The no-tillage treatment resulted in the highest grain yield each year. Lowest average yields resulted from rotary-tillage. Lowest annual yields resulted from rotary-tillage in 1979 and 1980, and from disk-tillage in 1981 (Table 4). The higher yield with no-tillage resulted from improved plant-water relationships, as suggested by the higher soil water content at sorghum planting and harvest (Table 3). Lower yields with other tillage treatments were associated with lower water contents at planting and harvest, and smaller changes during the growing season as compared with those for the no-tillage treatment. The generally low yields with all treatments in 1980 resulted from much below-average growing-season rainfall.

Forage yield trends did not follow grain yield trends, with disk-tillage resulting in highest and moldboard-tillage in lowest average yields. Forage yield differences among treatments were not significant in 1979. In 1980, some differences were significant with forage yields for sweep- and no-tillage treatments equally high and that for moldboard-tillage the lowest. Average forage yields in 1980 equaled those in 1979, even though rainfall in the 1980 growing season was much less than in 1979. In 1980, apparently most of the soil water was used for vegetative growth with relatively little remaining for grain filling. Hence, the low grain yields. Tillering resulting from above-average rainfall in 1981 resulted in much higher forage production than in other years with all treatments. Highest forage yields, however, were not directly associated with highest grain yields because grain on many tillers failed to reach physiological maturity by the time grain filling was halted by frost. This is confirmed by the low test weights for the disk- and rotary-tillage treatments discussed below.

Grain test weights, indicators of grain quality, averaged highest with no-tillage and lowest with disk- and rotary-tillage, and were significantly different in 1980 and 1981 (Table 4). In 1980, the test weight with rotary-tillage was lower than with no-tillage and, in 1981, it was lower with disk- and rotary-tillage than with other treatments. These trends were similar to the grain yield trends, with the low test weights with disk- and rotary-tillage in 1981 resulting from failure of the grain to reach physiological maturity before frost. This factor also resulted in the low weight/seed with disk- and rotary-tillage in 1981. As for test weights, weights/seed were not significantly different in 1979. However, sweep-tillage resulted in the highest and disk-tillage in a higher weight/seed than moldboard- and rotary-tillage in 1980. The trends in 1980 are not directly related to number of panicles, grain and forage yields, and grain test weights, and no reason for the trends is apparent. The generally high weights/seed with all treatments in 1980 are attributed to the major drought which limited tillering as indicated by the low number of panicles for that year. Seed on main-plant panicles are larger than those on tillers, especially when tillers develop late in the growing season. This was confirmed by calculations based on seed test weights and weights/seed.

Seed protein concentrations averaged highest with rotary-tillage and lowest with no-tillage. These trends are opposite the grain yield trends. Similar trends have been previously reported (Unger and Wiese, 1979).

Sunflower

Except for plants averaging significantly taller with the high- than with the low-residue treatment (1.28 and 1.26 m, respectively), neither the tillage nor the residue-level treatments significantly affected any measured sunflower growth, yield, or quality factor. There were, however, significant differences among years, and some trends for sunflower were different from the trends for sorghum.

In contrast to sorghum, sunflower plants were among the tallest and seed yields were the highest in 1980, even though rainfall was lowest during the 1980 growing season. The favorable growth and yields in 1980 are attributed to the ability of sunflower to extract water to greater depths of Pullman clay loam soil than sorghum (Unger, 1978b; Unger and Jones, 1981). With favorable soil water contents, sunflower has extracted water to a 3.0-m depth, whereas grain sorghum, under similar conditions, extracted water to only about a 1.2-m depth.

Water contents at planting of sunflower and sorghum were among the highest during the study in 1980 (Table 3). Although water contents in sunflower plots were higher than in sorghum plots (226 vs. 182 mm), the sunflower also extracted 63 mm more soil water than sorghum to the 1.8-m depth, the depth to which contents were determined. Extraction of water probably exceeded this depth and, therefore, contributed to the favorable growth and yield of sunflower in the low-rainfall season.

The deep rooting and deep water-extracting capability of sunflower, as compared to a crop such as sorghum, makes sunflower a desirable crop to use in a rotation. By extracting water from deep in the soil, some water that drains below the rooting depth of other crops is used for crop production and, therefore, the total amount of water available for crop production is increased.

The lower sunflower seed yield, test weight, weight/seed, and oil concentration in 1982 than in other years were not expected because soil water contents at planting (Table 3) and total growing season rainfall were relatively high that year. A possible reason was the much-below-average rainfall during August when seed filling occurred and for which adequate water is highly important (Unger, 1978b).

Wheat

Soil water contents after sunflower harvest were not significantly different due to the residual effects of the tillage and residue level treatments. Also, the subsequent wheat crop was uniformly managed, including irrigations for crop establishment and during the growing season. Therefore, differences in wheat growth and yield were neither expected nor found. Grain yields for wheat planted after sunflower averaged 3.21 and 5.90 Mg/ha in 1982 and 1983, respectively. Yields were mistakenly not obtained in 1981. The yields in 1982 and 1983 were comparable to those of wheat on other areas that were similarly managed. These results, therefore, indicate that planting wheat soon after sunflower harvest is a viable option, if the wheat is irrigated. Similar conclusions were reached from a wheat-sunflower rotation study (Unger, 1981). In contrast, planting wheat soon after sorghum harvest resulted in lower wheat yields in some cases because of later sorghum harvest dates, which delayed wheat planting past the optimum date, and because of the residual effects of atrazine on no-tillage treatment plots (Unger and Wiese, 1979). In this study, no residual effects of herbicides were noted in any phase of the study.

CONCLUSIONS

No-tillage, which maintained residues on the soil surface, was more effective than other tillage methods evaluated (moldboard-, disk-, rotary-, and sweep-) for improving precipitation storage as soil water during the 330-d fallow period from wheat harvest to sorghum planting in an irrigated winter wheat-dryland grain sorghum-dryland sunflower cropping system. Because of greater soil water storage, sorghum on no-tillage plots experienced less water stress during low rainfall periods of the growing season and, consequently, produced higher grain yields than sorghum with other tillage methods.

Removal of some wheat residues at the start of the fallow period decreased water storage during fallow. The greatest decrease occurred with the no-tillage system. However, residue removal did not significantly affect sorghum growth, yield, or quality factors, and had a relatively minor, although significant, effect on sunflower plant height.

Tillage treatments imposed after wheat harvest did not have a residual effect on sunflower grown after the sorghum, nor on the wheat planted soon after sunflower harvest. However, growing sunflower, which extends roots deeper than sorghum into Pullman clay loam, in the rotation resulted in more water extraction from deeper in the profile and, therefore, increased the total amount of water available for crop production.

A residual effect of tillage treatments on wheat was neither expected nor found because all plots were uniformly tilled and fertilized after sunflower harvest and because the wheat was uniformly planted and irrigated. Because sunflower was harvested by early September, wheat was planted near the optimum time and, consequently, yielded better on the average than did wheat for which planting was delayed due to delayed sorghum harvest in a previous study.

REFERENCES

1. Baumhardt, R.L. 1980. Influence of tillage and irrigation on grain sorghum production. M.S. thesis. Texas Tech. Univ., Lubbock.
2. Burwell, R.E., and W.E. Larson. 1969. Infiltration as influenced by tillage-induced random roughness and pore space. Soil Sci. Soc. Am. Proc. 33:449–452.
3. Edwards, W.M., and W.E. Larson. 1969. Infiltration of water into soils as influenced by surface seal development. Trans. ASAE 12:463–468.
4. Falayi, O., and J. Bouma. 1975. Relationships between the hydraulic conductance of surface crusts and soil management in a Typic Hapludolf. Soil Sci. Soc. Am. Proc. 39:957–963.
5. Foster, G.R., C.B. Johnson, and W.C. Moldenhauer. 1982. Critical slope lengths for unanchored cornstalk and wheat straw residue. Trans. ASAE 25:935–939, 947.
6. Greb, B.W., D.E. Smika, and A.L. Black. 1967. Effect of straw mulch rates on soil water storage during summer fallow in the Great Plains. Soil Sci. Soc. Am. Proc. 21:556–559.
7. Greb, B.W., D.E. Smika, and A.L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil Water Conserv. 25:59–62.
8. Johnson, C.B., J.V. Mannering, and W.C. Moldenhauer. 1979. Influence of surface roughness and clod size on soil and water losses. Soil Sci. Soc. Am. J. 43:772–777.
9. LeClerg, E.L., W.H. Leonard, and A.G. Clark. 1962. Field plot technique, 2nd ed. Burgess Publ. Co., Minneapolis, MN.
10. Linden, D.R. 1982. Predicting tillage effects on evaporation from the soil. p. 117–132. *In* P.W. Unger, D.M. Van Doren, Jr., F.D. Whisler, and E.L. Skidmore (ed.) Predicting tillage effects on soil physical properties and processes. Spec. Publ. 44. Am. Soc. of Agron., Madison, WI.
11. Mannering, J.V., and L.D. Meyer. 1963. Effects of various rates of surface mulch on infiltration and erosion. Soil Sci. Soc. Am. Proc. 27:84–86.
12. Meyer, L.D., W.H. Wischmeier, and G.R. Foster. 1970. Mulch rates required for erosion control on steep slopes. Soil Sci. Soc. Am. Proc. 34:928–931.
13. Moore, I.D., and C.L. Larson. 1979. Estimating micro-relief surface storage from point data. Trans. ASAE 22:1073–1077.
14. Musick, J.T., A.F. Wiese, and R.R. Allen. 1977. Management of bed-furrow irrigated soil with limited- and no-tillage systems. Trans. ASAE 20:666–672.
15. Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics, 2nd ed. McGraw-Hill Book Co., New York.
16. Unger, P.W. 1978a. Straw mulch rate effect on soil water storage during fallow and grain sorghum growth and yield. Soil Sci. Soc. Am. J. 42:486–491.
17. Unger, P.W. 1978b. Effect of irrigation frequency and timing on sunflower growth and yield. p. 117–129. *In* Proc. 8th Int. Sunflower Conf., Minneapolis, MN. July 1978. International Sunflower Association, The Hague, The Netherlands.
18. Unger, P.W. 1981. Tillage effects on wheat and sunflower grown in rotation. Soil Sci. Soc. Am. J. 45:941–945.
19. Unger, P.W. 1984. Tillage effects on surface soil physical conditions and sorghum emergence. Soil Sci. Soc. Am. J. (in press).
20. Unger, P.W., R.R. Allen, and A.F. Wiese. 1971. Tillage and herbicides for surface residue maintenance, weed control, and water conservation. J. Soil Water Conserv. 26:147–150.
21. Unger, P.W., and O.R. Jones. 1981. Effect of soil water content and a growing season straw mulch on grain sorghum. Soil Sci. Soc. Am. J. 45:129–134.
22. Unger, P.W., and A.F. Wiese. 1979. Managing irrigated winter wheat residues for water storage and subsequent dryland grain sorghum production. Soil Sci. Soc. Am. J. 43:582–588.